Sociotechnical typologies for national energy transitions

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1. Introduction

The energy landscape is changing dramatically. It is populated by many different and discrete energy transitions happening simultaneously in across different sectors, with dynamically different drivers, and across varying locations. This Perspective proposes a new three-part categorization to help better understand the myriad sociotechnical changes being witnessed, which cut across user and market behaviour as well as institutions and technologies. We express energy transitions in three categories: Interim energy transitions, caused by policies without public acceptance, mostly within non-democratic regimes. Deliberate energy transitions, caused by citizen-driven change without supporting policies. Transformative energy transitions stem from a combination of policy and citizen-driven change. The degree of permanence of these three transition types depends on the real and perceived benefits to energy users, sustained adoption of technology, and the regulatory regime. However, what is energy transition and why should we promote it?

Energy transition is a process that entails changes from one form, style, state, place or scale of energy system to another (Melosi 2010, Child and Breyer 2017). It is often accompanied by some form of energy system transformation in form, nature, appearance and character (often for the better), occurring at different scales within municipal, sub-national, national and international levels requiring multi-modal analysis at different scales (Child and Breyer 2017, Geels and Kemp 2006, Duan *et al* 2019). Indeed, human dimensions such as knowledge, motivation and contextual factors also impact on energy transitions (Steg *et al* 2015).

Energy transition often entails long term structural changes in energy systems leading to a shift in production and consumption patterns towards low-carbon energy sources (Davidsson 2014, Edomah 2019, Grubler 2012). One of the more established definitions is that energy transitions entail a change in fuels and associated technologies, such as switching from the use of fuel wood to petroleum products or changing from steam engines to internal combustion engines (Hirsh and Jones 2014, Edomah 2020). Others argue that a transition entails a shift in fuels and sources of primary energy supplies (Miller *et al* 2015), a change in patterns of energy use among energy users in society (O'Connor and Cleveland 2014, O'Connor 2010), or a switch in economic systems or markets depending on one form of energy source/technology or another (Pearson 2012). A major factor used in defining and ascertaining the sustainability of an energy transition is its temporality. Several related questions arise. How does the pace of change impact on energy transition dynamics? How long is optimal for different types of energy transitions?

Defining or at least grappling with the timing and contextual specificity of energy transitions can be difficult (Sovacool 2016). This is because energy transition occurs in different ways and the timing and duration of transition is highly dependent on contextual norms within different energy geographies (Verbong and Geels 2007, Steg *et al* 2015). Stylized phases, path dependency, lock-in and subversion, which attempt to explain the way with which the principles and values of energy systems in place are contradicted and reversed, may play a vital role in defining the temporality or permanence of energy transitions. Indeed, there has been conflicting evidence with respect to the timing of energy transitions (Sovacool 2016).

In challenging some misleading understanding of the concept of energy transition, York and Bells argue that it is important to be able to distinguish between energy transitions and mere energy additions (York and Bell 2019). As evidence to this claim, historical changes in energy systems that happened in the nineteenth and twentieth centuries were based on an addition (and increased share) of new energy fuels and technologies in the energy mix (York and Bell 2019). Indeed, this suggests that a transition away from fossil fuels may require much more than growth in renewables.

While several papers have explored the notion of timing (World Economic Forum 2013), temporality (Sovacool 2016) and geographies of energy transitions (Bridge *et al* 2013), less work has investigated possible types of energy transitions and the forms in which they manifest. Defining a typology of energy transitions enables us to carry out a systematic classification of the various types by their causes, effects, actors, and spatial implications at the analytical, normative, practical, and policy levels. In this Perspective, we present a framework of three types of energy transitions defined by the degree of *willingness* of energy consumers to accept (behavioural) change, *regulatory/policy backing* supporting such changes in energy use patterns, and temporality.

2. Sociotechnical types of energy transitions

We argue that there are three types of energy transitions primarily defined by sociotechnical aspects. The three types of energy transition are:

- Interim energy transition
- Deliberate energy transition
- Transformative energy transition

Table 1 summarizes the high-level aspects of these transition types, and the sections to come explore them in more detail.

Table 1: Conceptual sociotechnical types of energy transitions (Source: author compilation)

Energy transitions types	Cause(s)	Effect(s)	Spatial implication(s)	Actors	Examples
Interim energy transition	Policies without public acceptance in the form of imposed rules and political	Momentary/temporary change in energy use patterns that lasts for a short time Energy users switch back to business as usual at the	Occurs at a small (micro) scale, at individual, household or municipal level Technological adoption	Individual citizens, pressure groups, and policy makers in municipal	Municipal laws abolishing the use of kerosene lamps for

	pressures	slightest opportunity	and behavioural change is driven by external (e.g., municipal) interests	councils	lighting or fuel wood for cooking
Deliberate energy transition	Citizen/user-driven change without supporting regulations	Leads to a change in energy use patterns where energy users evaluate the cost and benefits that new (additional) technology adoption or behavioural change confers The timing could last from a few months to years depending on the benefits derived.	Occurs at a middle (meso) scale, at sub-national levels Technology diffusion is driven by sub-national energy targets	Individual citizens, Community cooperatives, policy makers within sub-national governments , and NGOs	Community renewable energy projects. Electric and hybrid cars purchase decisions
Transformative energy transition	A combination of policy and citizen-driven change	Leads to a sustained (or longer) change in energy use patterns where energy users know, understand and appreciate the benefits derived from such changes. The timing could last for some decades.	Occurs at a large (macro) scale, at national, regional and international levels Large scale deployment is driven by international agreements and interest of transnational firms and NGOs	Individual citizens, national and regional governments, multilateral agencies (IRENA, IEA), environmental advocacy groups, NGOs	National renewable energy targets Retiring coal fired power plants

2.1. Interim energy transitions

This is a form of energy transition that results from policies without public acceptance in the form of imposed rules and political pressures on energy users. This is common within non-democratic settings. These imposed rules could be *intentional* or *unintentional*. It is intentional when the imposed regulations are aimed at achieving a set objective in energy consumption pattern and use. It is unintentional when imposed rules and other forms of political pressures lead to unintended consequences in energy use. This form of energy transition may also occur in a case where there are no imposed regulations. It may result through some form of political pressure and persuasion from friends or pressure groups to adopt a new technology or change energy use behaviour. Some examples of interim energy transition include municipal laws abolishing the use of kerosene lamps for lighting purpose, or laws restricting the use of fuel wood for cooking.

This form of energy transition occurred across several geographies during the lockdown period of the 2020 coronavirus (COVID-19) pandemic (Guo *et al* 2020). Imposed rules in the form of forced lockdown measures resulted in many families being confined to their homes which led to a consequent change in energy use patterns across several sectors. Indeed, the International Energy Agency (IEA), in the 2020 Global Energy Review report on the impact of COVID-19 crisis on global energy demand and CO_2 emissions, argued that energy demand reduced by an average of 25% (in countries with full lockdown) and 18% (in countries with partial lockdown) per week respectively (IEA 2020). The IEA further argued that the decline in energy demand was dependent on the stringency and duration of lockdowns. According to the IEA report (which evaluated energy dynamics in 30 countries), electricity demand reduced by at least 20% in several countries with full lockdown (IEA 2020). The upsurge in residential electricity demand far outweighed the reductions recorded in industrial and commercial sectors. The shift of some professional and educational services to the homes led to a temporary surge in residential energy consumption (Edomah and Ndulue 2020). Many educational institutions switched to online or distance learning mode while some professional services by persons in different organizations shifted to the homes, resulting in some new patterns of working and learning. This resulted to increased heating/cooling requirements for more people spending the greater part of the time in their homes. Consequently, the forced lockdown (imposed rules) led to an interim change in energy consumption patterns and a consequent reduction in carbon emissions in the industrial sector.

2.2. Deliberate energy transitions

Deliberate energy transition is caused by citizen-driven change without supporting regulations. It occurs when there is an intentional (behavioural) change or adoption of a new technology as a result of some perceived benefits to be derived which are not yet backed by regulations. In this form of energy transition, energy users are prompted to act based on some perceived benefits they may derive. Arguably, their decisions are mainly driven by cost-benefit analysis and rational choice, and not just about the environmental benefits or climate impact that the technological switch or behavioural change provides. Some examples of deliberate energy transition include community renewable energy projects and individual purchase decisions leading to the adoption of hybrid and electric cars (Mersky *et al* 2016, Soltani-Sobh *et al* 2017, Rezvani *et al* 2015).

Using the example of the adoption of hybrid and electric cars, it can be observed that widespread adoption is not only a result of policies which provides an option for their use. It is mainly the result of a deliberate decision by end users who have decided to try it out in order to ascertain the (status, fuel cost, maintenance cost and environmental) benefits which it confers (Mersky *et al* 2016, Soltani-Sobh *et al* 2017). Rezvani et al, in their work on the drivers and barriers against consumer adoption of plug-in electric vehicles (EVs), argues that emotion, symbolic meaning, innovativeness, identity, and pro-environmental attitudes are key drivers of EV adoption (Rezvani *et al* 2015). Rezvani further argued that positive emotions from driving electric cars, pride and joy, positively influenced its adoption. In the European Union, understanding local conditions and addressing regional variations are specific drivers of hybrid and electric vehicle adoption (Coffman *et al* 2017). Meanwhile, in the United States, the presence of some government incentives and other socio-economic factors has been the main driver of electric vehicle adoption (Soltani-Sobh *et al* 2017). Establishing these benefits could mean that technological switch or behavioural change may have to be observed over time in order to ascertain the real benefits, which could last for several years. This is the main factor that is responsible for a longer timeframe of deliberate energy transition when compared with the interim energy transition.

2.3. Transformative energy transitions

Transformative energy transitions are more sustained. They occur as a result of a combination of policy and citizen-driven change. In this case, energy users know and understand the benefits of adopting a certain technology or embracing change in energy consumption patterns. The energy consumers willingly accept (behavioural or technological) change, not only because of the perceived benefits they stand to derive but, above all, because the intentional change and the corresponding benefits are backed by regulations. Some examples of transformative energy transitions include country or regional level decisions to retire coal-fired power plants. Other examples include national renewable energy targets defining the target percentage of renewables in the national energy mix. Figure 1 shows a mapping of the sociotechnical types of energy transitions.

Using the example of the adoption of solar photovoltaic solutions across many parts of Africa, it is argued that this technology have the potential of providing a quick win in addressing the energy access challenge. The adoption rate has been impacted by the acceptance of this new technology by energy users in the forms of solar home systems (SHS), solar minigrids, and solar hybrid power solutions (Oyewo *et al* 2020). The energy users accept these forms of technologies due to the perceived (and actual) benefits that can be derived from them. The adoption is further entrenched by different multilateral agencies, non-governmental organizations and energy/environmental advocacy groups providing financing facilities for various solar projects. In Nigeria, the possibility of household use of solar solutions for lighting, energising rechargeable appliances, and cooling of houses have been the main driver of solar technology adoption among end users (Barau *et al* 2020). In Central East Africa, the adoption of the Pay-As-You-Go Solar Home Systems is driven by its disruptive positive impact in ensuring access to clean affordable energy for the poor population (Barrie and Cruickshank 2017). Another factor supporting widespread adoption is government regulations, supporting the use of different forms of solar solutions as a strategy for addressing the challenge of energy access. This multi-faceted approach of wilful behavioural change and new technological adoption, backed by government regulations, can lead to a more sustained energy transition. This is the reason this type of transition can last for several decades.

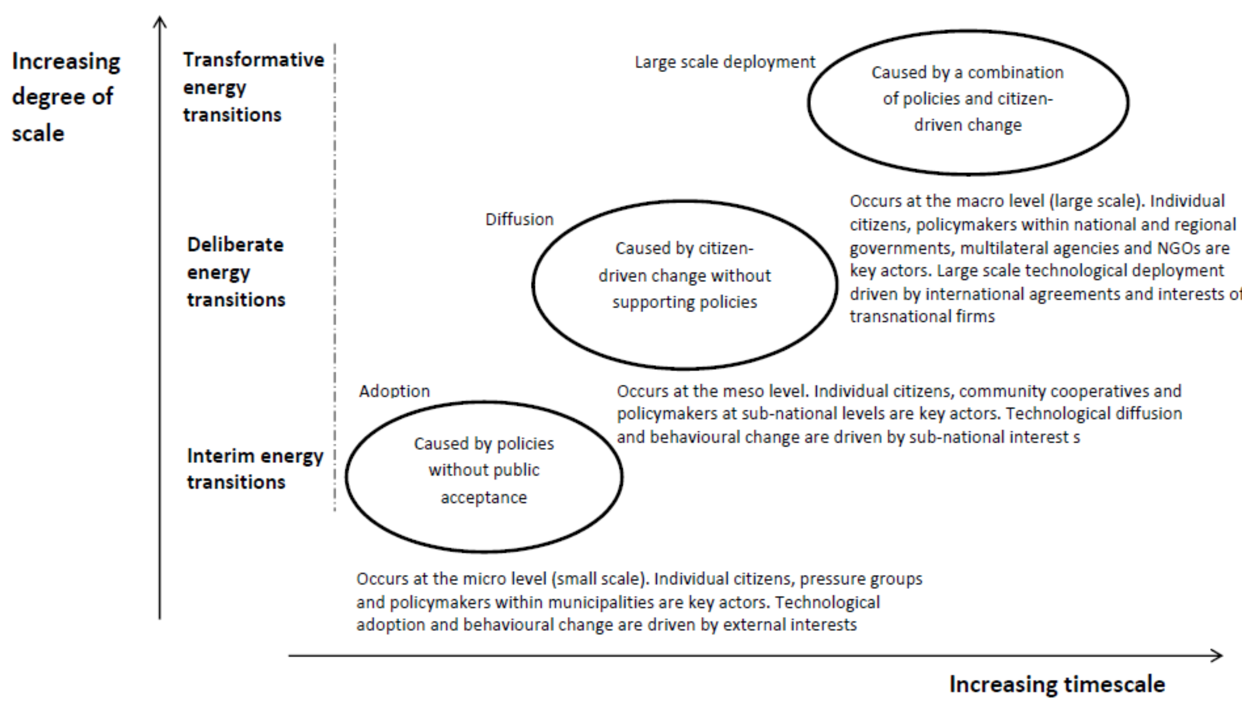

Figure 1: Mapping of the sociotechnical types of energy transitions (source: authors)

3. Implications for the study of energy transitions

The use of three sociotechnical types of energy transitions enable us to analytically capture the polycentric roles of individuals, groups (actors), geographical units (municipalities, states, countries, etc.), social interactions (energy behaviour) and material artefacts (energy technologies) as the units of analysis as shown in Figure 1. It shows how such transitions involve not only technical dynamics and social acceptance, but important coordination effort among diverse actors that tough upon governance and forms of collaboration (or resistance).

The proposed typology also captures better the *temporal and spatial dynamics* of energy transitions. It envisions transitions not only as a substitution of fuels or an alteration of energy systems, but also the reconfiguration of scale and patterns of activities (Bridge *et al* 2013). In terms of spatial dimensions, interim energy transitions occur at the micro (small) scale. At this scale, behavioural and technological change is driven by external pressures from individual, household and municipal interests. Deliberate energy transitions occur at the middle (meso) scale. In this type of transition, technological diffusion is driven by sub-national energy interests and targets. Transformative (or a more sustained) energy transition occurs on a large (macro) scale, mainly at national, regional and international levels. Large scale technological deployment is driven by international agreements and interests of transnational firms and non-governmental organizations.

Complementarity in energy transition is another important feature arising from our typology. How do complementary and/or competing technologies impact on the type of energy transition we end up with? Arguably, within some contexts, it is possible that solar and wind are complementary technologies while in other contexts, solar and hydro may be competing against each other. In considering the effect of inter-niche competition in transitions, Lin and Sovacool argue that it is important to understand the socio-technical barriers, benefits and drivers that shape energy technology transition. (Lin and Sovacool 2020) Sander and Hillman argue that technological interaction, which provides a basis for complementarity or competition, is a result of some overlapping value chains and socio-technical elements. (Sandén and Hillman 2011) These technological interactions, according to Sander and Hillman, could be expressed in forms of: symbiosis (with two technologies positively affecting each other); neutralism (where none is affected by the other); parasitism (where one technology is inhibited while the other benefits); commensalism (one technology is benefits while the other is not affected); and amensalism (one technology is inhibited while the other is not affected). Indeed, with respect to competition, two technologies affect each other negatively. (Sandén and Hillman 2011, Lin and Sovacool 2020)

It is important that we consider the *contextual dimensions* about the various types of energy transitions. Contextual norms, spatial narratives across different energy geographies, diverse path dependent trajectories, and complementary and competing technologies lead to different pathways that define and shape future energy systems.

4. Conclusion

Ultimately, our typology of transitions suggests that these polycentric aspects, their spatial and temporal dynamics, and complementarity of fuels and technologies all shape energy transitions. They shape contextual norms, spatial narratives across different energy geographies, diverse path dependent trajectories, and complementary and competing technologies lead to different pathways that define and shape future energy systems.

In this Perspective, we proposed a three-fold categorization of energy transitions that have both conceptual utility but also policy applicability. There is a need for policymakers to understand how policies without public acceptance can lead to interim energy transition and how citizen-driven change without supporting policies leads to deliberate energy transition. Indeed, policymakers would prefer a combination of policies and citizen-driven change which lead to a more sustained form of energy transition. The three types of energy transitions presented can help policymakers and other energy stakeholders to provide adequate (socio-technical and policy) responses that addresses evolving issues at various points of the energy transition process. It is also believed that the typology proposed can be used to inform future research or policy agendas.

Author contributions:

Norbert Edomah conceived the idea and wrote some sections of the Perspective. Morgan Bazilian provided some concrete examples on the different types of energy transition in section 2 and also fine-tuned the conclusion. Benjamin provided some concrete insights on the ideas presented in sections 2 and 3.

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